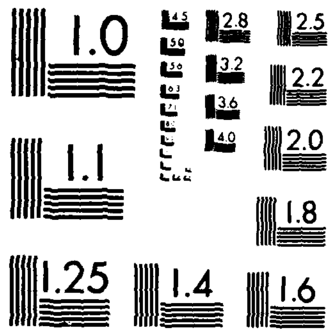
AD-A174 488 HOT ELECTRON EMISSION IN SEMICONDUCTORS(U) INNSBRUCK UNIV (AUSTRIA) INST OF EXPERIMENTAL PHYSICS E GORNIK ET AL 30 JUN 86 DAJA45-84-C-0052 1/1

UNCLASSIFIED F/G 20/12 NL



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

AD-A174 488

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER 4	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Hot Electron Emission in Semiconductors		5. TYPE OF REPORT & PERIOD COVERED Fourth Interim Report 5 Dec. 1985 - June 1986
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Prof. Dr. E. Gornik Robert Christanell Mag. Manfred Helm Karl Unterrainer		8. CONTRACT OR GRANT NUMBER(s) DAJA 45-84-C-0052
9. PERFORMING ORGANIZATION NAME AND ADDRESS		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS USARDSG-UK Box 65, FPO NY 09510		12. REPORT DATE June 30, 1986
		13. NUMBER OF PAGES 4
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

This document has been approved for public release and sale; its distribution is unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

- novel tunable FIR sources
- hot electron emission in GaAs/GaAlAs heterostructures
- streaming of hot carriers in crossed electric and magnetic fields
- new theory for Landau level inversion by electrical pumping in crossed electric and magnetic fields

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

see reverse side

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

Sub µm sinusoidal gratings were prepared on GaAs/GaAlAs heterostructures. Experiments to demonstrate a Smith-Purcell-effect in a semiconductor are in preparation. FIR emission due to streaming of hot carriers in crossed electric and magnetic fields has been observed on large p-Ge samples. Stimulated emission has not been achieved yet. A new theory of the crossed field configuration (electric and magnetic) describing the Landau levels in a quantum mechanical manner was developed. It is shown that population inversion between Landau levels can be achieved, if scattering by optical phonons and a quasielastic scattering process are taken into account.

A-1

"HOT ELECTRON EMISSION IN SEMICONDUCTORS"

4th Interim Report

1 Dec. 1985 - 30 June 1986

Summary of the scientific work

The research work on "Hot Electron Emission in Semiconductors" was continued with the following topics:

a) The emission due to the interaction of drifting carriers in GaAs/GaAlAs heterostructures with a periodic grating

b) FIR emission due to streaming of hot carriers in crossed electric and magnetic fields in p-Ge

c) Development of a new model for a streaming induced population inversion between Landau levels

ad a) With the help of a reactive ion etching (RIE) process the surface of GaAlAs/GaAs heterostructures is sinusoidally modulated. Through the control of process parameters the profile and height of the modulation can be varied between 50 and 500 Å. The periodicity is variable between 0.18 and 0.7 μm due to the laser holographic technique (HeCd UV Laser λ = 325 nm). The first goal of the presently running experiments is the observation of laterally modulation 2D-density in the GaAs-channel due to the modulated GaAlAs thickness. The next step is the application of an electric field to achieve a carrier drift. In high mobility samples ($\mu_{4.2K} \sim 1.2 \times 10^6 cm^2/Vs$) a drift velocity of $1.5 \times 10^7 cm/s$ can be achieved with moderate electric fields /1/.

The observation of far infrared radiation due to the drift of a modulated density distribution is the main goal of this part of the project.

At present we are not able to observe any radiation due to this effect which is known in the literature as Smith-Purcell effect /2/. To understand the lack of radiation we have performed calculations in the classical limit /3/: The far infrared radiation of a drifting modulated electron plasma was calculated to 100 pW/cm^2 if the only mechanism for radiation generation is the induced image potential. However, if the induced image potential is amplified by the grating which dynamically influences the electron distribution back, intensities of up to 100 mW/cm^2 become possible. Whether these amplification mechanisms can be induced depends critically on the form of the grating and the distance from the channel. At present we are processing samples to control the etch rate in an anodic oxidation process on the scale of 10 Å.

b) The aim of this part of the project is to investigate the FIR emission from hot holes in p-Ge under crossed field ($E \perp B$) conditions, and, if possible, develop a coherent far infrared source.

There was not too much progress in this part of the project. According to most recent publications /4,5/ the necessary sample sizes are considerably larger than we have used them. We have prepared in the meantime a sample 2 cm long and 2 x 2 mm^2. With this sample and a new pulse generator which provides peak pulse powers of 100 kW we hope to be able to achieve the lasing condition. The physics of this laser operation is not well understood yet.

In the future we want to investigate the time- and spectral dependence of the stimulated emission and demonstrate spectroscopic applications.

Russian authors claim to achieve peak powers in the far infrared of up to 10 W, which would enable even nonlinear spectroscopy.

ad c) In crossed electric and magnetic fields not only a population inversion between the light and heavy hole band of p-Ge can arise, but also an inversion between Landau levels in a pure semiconductor has been predicted /6/. This inversion is based on the interaction of the electrons with optical phonons, and should appear when $\zeta = v_{op}B/E \lesssim 2$. Up to now this process was described qualitatively in the streaming motion picture. Monte Carlo /7/ and Boltzmann equation /8/ studies also led to an inverted distribution function. All theoretical investigations of this problem in the past were performed in the limit of a non-quantizing magnetic field. If one wants to study optical transitions between (inverted) Landau levels, however, it is of fundamental importance to consider the discrete structure of the energy levels.

We have treated the crossed field situation in a fully quantum mechanical frame, which means that we start from the Liouville equation for the density operator /9/. In the case of weak electron-phonon coupling this can be transferred into a master equation for the diagonal elements of the electron density matrix /10/ which correspond to the occupation numbers of the different Landau levels. We have neglected the dependence of the quantum number k_z, as a consequence the system of coupled integral equations is simplified to algebraic equations. This is solved for three Landau levels taking into account the scattering by optical and acoustic phonons.

A central result of our calculation is that a quasielastic scattering mechanism (like acoustic phonon scattering) is necessary to achieve population inversion. This stands in contrast to previous calculations performed in the limit of

non-quantizing magnetic field. Further it turns out that inversion is not restricted to $\zeta \approx 2$, but can also occur at somewhat smaller or larger values of ζ. These features seem to be a direct consequence of the discrete structure of the energy spectrum.

It is planned to extend this promising model by including the k_z-dependence and more than three Landau levels.

M. Helm
K. Unterrainer
R. Christanell
E. Gornik

References

/1/ M. Inoue et al., Jap.J.Appl.Phys. 22,213(1983)
/2/ S.J. Smith, E.M. Purcell, Phys.Rev. 92,1069(1953)
/3/ G.W. Stroke, Handbuch der Physik XXIX, Springer 1967(p440)
/4/ A.A. Andronov et al., Physica 134B, 210 (1985)
/5/ S. Komiyama, Appl.Phys.Lett. 47, 958 (1985)
/6/ S. Komiyama, Adv.Phys. 31, 255 (1982)
/7/ P. Warmenbol, F.M. Peeters and J.T. Devreese, Phys.Rev. B 33, 1213 (1986)
/8/ F. Brosens and J.T. Devreese, Solid State Commun. 44, 597 (1982)
/9/ M. Helm and E. Gornik, to be published
/10/ D. Calecki, in "Physics of Nonlinear Transport in Semiconductors", ed. D.K. Ferry, J.R. Barker and C. Jacoboni (Plenum Press, New York 1980) p. 289.

END

12-86

DTIC